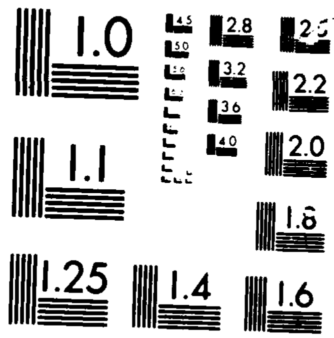
AD-A168 982 MICROWAVE LOSS PROPERTIES OF HEXAGONAL FERRITES FOR MILLIMETER WAVE APPLI..(U) COLORADO STATE UNIV FORT COLLINS DEPT OF PHYSICS C E PATTON 15 MAR 86 1/1

UNCLASSIFIED ARO-21210.2-MS DAAG29-84-K-0172 F/G 20/2 NL



MICROCOP

ARO 21210.2-MS

2

AD-A168 982

MICROWAVE LOSS PROPERTIES OF HEXAGONAL FERRITES

FOR

MILLIMETER WAVE APPLICATIONS

Final Report

March 10, 1986

U. S. Army Research Office

Contract DAAG29-84-K-0172
(ARO Proposal No. 21210-MS)

August 15, 1984 to February 14, 1986

Carl E. Patton
Department of Physics
Colorado State University
Fort Collins, Colorado 80523

Approved for Public Release
Distribution Unlimited

86

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER ARO 21210.2-MS	2. GOVT ACCESSION NO. N/A	3. RECIPIENT'S CATALOG NUMBER N/A
4. TITLE (and Subtitle) Microwave Loss Properties of Hexagonal Ferrites for Millimeter Wave Applications		5. TYPE OF REPORT & PERIOD COVERED Final Report - Aug. 15, 1984-Feb. 14, 1986
		6. PERFORMING ORG. REPORT NUMBER N/A
7. AUTHOR(s) Carl E. Patton		8. CONTRACT OR GRANT NUMBER(s) DAAG29-84-K-0172
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Physics Colorado State University Fort Collins, CO 80523		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS N/A
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Office Post Office Box 12211 Research Triangle Park, NC 27709		12. REPORT DATE March 15, 1986
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if differ from Report)

NA

18. SUPPLEMENTARY NOTES

The view, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Hexagonal ferrite, Millimeter wave ferrite materials, Off-resonance, microwave losses, Microwave damping

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This short term post LRCP contract was designed to explore the application of the off-resonance effective linewidth technique to hexagonal ferrite materials at x-band frequencies. This objective has been accomplished. It has been demonstrated that the technique works quite well for both uniaxial and planar ferrite materials. The key result for millimeter wave applications is that a significant part of

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) the microwave losses in these materials appears to be related to inhomogeneities. The effective losses which would determine insertion loss parameters for off-resonance device applications would appear to be much lower than one would infer from a direct ferromagnetic resonance linewidth determination. It was also possible to use the technique to measure the off-resonance loss properties in uniaxial materials at x-band, even though the large anisotropy fields precluded the observation of the FMR peak. The application of the technique to planar samples has also led to a new approach to the analysis of fundamental microwave relaxation processes in ferrite materials. Two short publications have resulted from this work, and a Ph.D. thesis is in preparation.

ABSTRACT

This short term post LRCP contract was designed to explore the application of the off-resonance effective linewidth technique to hexagonal ferrite materials at x-band frequencies. This objective has been accomplished. It has been demonstrated that the technique works quite well for both uniaxial and planar ferrite materials. The key result for millimeter wave applications is that a significant part of the microwave losses in these materials appears to be related to inhomogeneities. The effective losses which would determine insertion loss parameters for off-resonance device applications would appear to be much lower than one would infer from a direct ferromagnetic resonance linewidth determination. It was also possible to use the technique to measure the off-resonance loss properties in uniaxial materials at x-band, even though the large anisotropy fields precluded the observation of the FMR peak. The application of the technique to planar samples has also led to a new approach to the analysis of fundamental microwave relaxation processes in ferrite materials, Two short publications have resulted from this work, and a Ph.D. thesis is in preparation.

TABLE OF CONTENTS

I. INTRODUCTION

This contract was the outgrowth of a visit of the principal investigator to the Electronics Technology and Devices Laboratory (ETDL), LABCOM, U.S.Army, Ft. Monmouth, NJ during the summer of 1984 as part of the Army's Laboratory Research Participation Program (LRCP). It became clear during that visit that one key problem for ferrite materials applications at millimeter wave frequencies concerns the magnetic loss. Previous ferromagnetic resonance (FMR) linewidth data indicated that these losses were too large for efficient device operation. These large losses appeared to be connected primarily with inhomogeneity considerations. For many classes of ferrite devices, however, the material can be field biased away from ferromagnetic resonance such that these inhomogeneity related losses are not operative, at least in principle. An off-resonance effective linewidth parameter, rather than the FMR linewidth, would be a more meaningful loss parameter for such device purposes.

The objective of this contract was to examine this effective linewidth proposition experimentally. The data were obtained on candidate hexagonal ferrite materials with potential millimeter wave applications, but the actual measurements were carried out at 10 GHz, in the microwave regime, where the required measurement capability had already been established with previous ARO support. One publication has resulted from this 18 month and relatively low budget effort. A second report will be presented at the upcoming INTERMAG conference in Phoenix, AZ, April, 1986. Two spin-off proposals for ARO consideration have resulted from this work, one under the DOD University Research Instrumentation Program (URIP) to establish a millimeter wave magnetic and dielectric materials measurement facility at Colorado State University and one to extend the measurements reported herein to the actual millimeter wave frequencies of interest.

II. RESULTS

This section presents a summary of the key results of the work on this contract. Part II.(a) contains a reprint of the article, "Off Resonance Relaxation in Hexagonal Ferrites", which was presented at the International Conference on Magnetics, San Francisco, September, 1985, and which recently appeared in print [M. V. Kogekar and C. E. Patton, J. Mag. Magn. Mater. 54-57, 1139 (1986)]. Part II.(b) contains a copy of the two page digest of the paper which will be presented at the upcoming INTERMAG conference. "An Experimental Investigation of Phenomenological Damping in Ferrites", also by M. V. Kogekar and C. E. Patton.

II.(a) Off Resonance Relaxation in Hexagonal Ferrites, Reprint.

Journal of Magnetism and Magnetic Materials 54–57 (1986) 1139–1140

OFF RESONANCE RELAXATION IN HEXAGONAL FERRITES

M.V. KOGEKAR and C.E. PATTON

Department of Physics, Colorado State University, Fort Collins, CO 80523, USA

The effective linewidth technique has been applied to study field dependent microwave losses in hexagonal ferrites for the first time. Data have been obtained on single crystal Zn_2–Y and ZnTi–M as well as oriented polycrystalline NiCo–W materials. The results clearly show that the high field effective linewidth is significantly lower than the ferromagnetic resonance (FMR) linewidth. This implies that inhomogeneity or two-magnon relaxation contributes significantly to the FMR linebroadening and that the intrinsic linewidth is much lower than the FMR linewidths. The results also demonstrate the usefulness of the effective linewidth technique to study microwave losses even under conditions where the actual FMR peak is inaccessible.

1. Introduction

Microwave losses and relaxation in hexagonal ferrites have been the subject of extensive research, partly because of the potential applications of these materials at millimeter wave frequencies. In most cases, previous relaxation data were obtained by ferromagnetic resonance (FMR) experiments, and the FMR linewidth was taken as a measure of the relaxation. The FMR linewidth reported for such materials (both single crystals and polycrystals), however, are relatively large, possibly due to linebroadening due to inhomogeneities and/or two-magnon processes, and do not represent the intrinsic losses in these materials. There exists a more powerful technique than FMR, the effective linewidth method, which enables one to measure the relaxation rate for the driven uniform precession mode as a function of the applied field, both near and far from the FMR position. This technique has been shown to be quite useful for the study of two-magnon linebroadening, microstructure effects on losses, and intrinsic relaxation in polycrystalline garnets and spinels [1–4].

The purpose of this work was to use the effective linewidth technique to measure the field dependence of the microwave relaxation processes in hexagonal ferrites, and thereby determine both the two-magnon losses and the intrinsic losses in these materials. The technique makes it possible to determine the off-resonance losses at the operating frequency of 9.9 GHz, even for high anisotropy uniaxial materials for which the actual FMR peak is inaccessible by conventional resonance techniques.

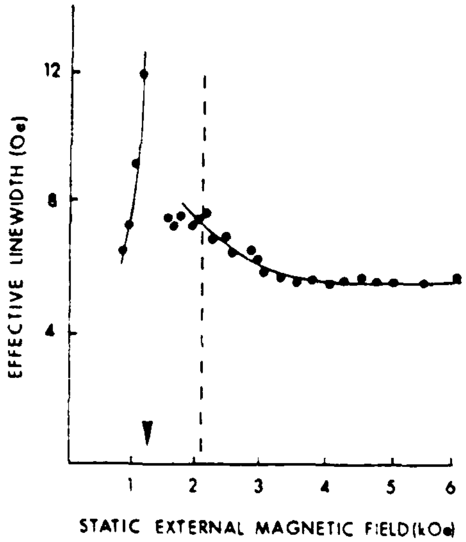


Fig. 1. Effective linewidth as a function of applied field for single crystal Zn_2–Y sphere with planar anisotropy. The pointer above the field axis represents the position of FMR field at 9.9 GHz. The broken vertical line indicates the field at which the bottom of the spin wave manifold lies at 9.9 GHz.

2. Experiment and results

The effective linewidth (ΔH_{eff}) values were obtained as a function of applied magnetic field, using the high Q cavity feedback technique described in ref. [5]. The measurements were done at a microwave frequency of 9.9 GHz and room temperature. Data were obtained on three classes of hexagonal ferrite materials, single crystal Zn_2–Y with planar anisotropy, single crystal ZnTi–M with uniaxial anisotropy and oriented polycrystalline NiCo–W with uniaxial anisotropy.

Fig. 1 shows the effective linewidth as a function of applied field for a Zn_2–Y sphere with planar anisotropy, magnetized in the easy plane. Planar anisotropy samples are of interest because in spite of the large anisotropy, the FMR field and the field interval over which low wave number magnons are degenerate with the uniform mode at the operating frequency are accessible at 9.9 GHz, in addition to the higher and lower field regimes for intrinsic losses. For the Zn_2–Y sphere magnetized in the easy plane, the saturation induction of 2.34 kG and the anisotropy field of 9 kOe yield an FMR field position of 1.23 kOe at 9.9 GHz, which is marked by a pointer above the field axis in fig. 1. The broken vertical line in the figure indicates the

0304-8853/86/$03.50 © Elsevier Science Publishers B.V.

field at which bottom of the spin wave manifold is at 9.9 GHz. The effective linewidth increases with field as the FMR point is approached from below and drops off as one moves away from the FMR position toward higher field values. In the vicinity of the FMR field position the effective linewidth is rather high. The gap in ΔH_{eff} data around the FMR field position is due to extreme degradation in the cavity Q because of the high losses at resonance. Presumably, the effective linewidth in this region is comparable to the actual measured FMR linewidth of 60 Oe. The drop in ΔH_{eff} at fields above FMR extends somewhat beyond the point at which the spin-wave band moves above 9.9 GHz (dotted line). The effective linewidth above about 4 kOe is relatively constant at $\Delta H_{eff} \approx 5$–6 Oe, independent of field.

The above results show two significant effects. First, the large ΔH_{eff} values in the FMR-region with degenerate spin waves available as a relaxation channel and the drop off in ΔH_{eff} at higher and lower fields indicate that two-magnon losses are important for hexagonal ferrites. Second, the high field ΔH_{eff} value of 5–6 Oe indicates that the intrinsic losses are much smaller than one would infer from FMR alone.

In contrast with the planar case, for high anisotropy uniaxial hexagonal ferrites the FMR field is not accessible at 9.9 GHz by standard microwave techniques. (Negative fields or circular polarized excitation would be required.) In spite of this, it is possible to do the effective linewidth experiments on such materials at x-band frequencies. Fig. 2 shows the ΔH_{eff} vs. field results for an oriented polycrystalline NiCo-W sphere with the applied field along the average easy axis direction. This sample has a saturation induction and anisotropy field of 3.4 kG and 4.0 kOe, respectively, corresponding to an FMR-field of -0.4 kOe. The cut-off field for degenerate magnons is about 3 kOe, at the left hand field limit of the figure.

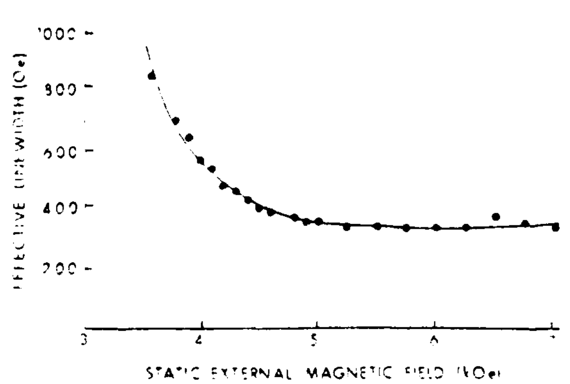


Fig. 2. Effective linewidth vs. field for an oriented polycrystalline NiCo-W sphere with uniaxial anisotropy.

The variation of ΔH_{eff} vs. field in fig. 2 is similar to that in fig. 1, with the important difference of no accessible FMR. The size of ΔH_{eff} is much larger. We see the characteristic drop in ΔH_{eff} with increasing field and a leveling off at $\Delta H_{eff} \approx 400$ Oe for fields above 5 kOe or so. The increase at low fields is probably due to a combination of demagnetizing effects (lack of saturation) and inhomogeneous and/or two-magnon linebroadening. Even though the field is above the cut-off for degenerate magnons, the linewidths are so large that the cut-off is smeared out and substantial linebroadening is still in evidence [1,6]. The fact that the intrinsic linewidth is lower than the FMR linewidth (≈ 2000 Oe) by a factor of five implies that the major sources of loss in these materials are probably two-magnon related relaxation processes and/or inhomogeneity linebroadening.

The effective linewidth vs. field was also measured for a single crystal ZnTi–M platelet with a high uniaxial anisotropy field of 11 kOe. For this value of anisotropy field, the FMR absorption curve is totally inaccessible, since the resonance would occur at negative 9 kOe. The effective linewidth, however, was readily measurable over a field interval of 2–8 kOe and found to be approximately 200–400 Oe. A characteristic increase with field, noted previously for conventional ferrites [7], was also observed. These results demonstrate the usefulness of present techniques in determining the off resonance losses far away from resonance and in the absence of any degenerate spin waves. The large ΔH_{eff}-values also show that the intrinsic losses in some single crystals can be large, even in the absence of inhomogeneity contributions.

The authors are indebted to Dr. W. Tolksdorf, Philips GmbH Forschungslaboratorium, Hamburg, Fed. Rep. Germany, Dr. Arthur Tauber, US Army Electronics Command, Fort Monmouth, New Jersey, and Mr. L. Reese Hodges, Trak Microwave Corporation, Tampa, Florida for providing the ferrite samples used in this study. The work was supported in part by US Army Research Office, Contract DAAG-29-84-K-0172 and the National Science Foundation, Grant DMR-8013727.

[1] K. Motizuki, M. Sparks and P. Seiden, Phys. Rev. 140 (1965) 972A.
[2] Q.H.F. Vrehen, IEEE Trans. Magn. MAG-4 (1968) 479.
[3] T. Kohane and E. Schlömann, J. Appl. Phys. 38 (1968) 720.
[4] C.E. Patton, Phys. Rev. 179 (1969) 352.
[5] C.E. Patton and T. Kohane, Rev. Sci. Instr. 43 (1972) 76.
[6] E. Schlömann, J. Appl. Phys. 40 (1969) 1422.
[7] [illegible] and C.E. Patton, Adv. Ceramics 15 (1985) in press.

II.(b) An Experimental Investigation of Phenomenological Damping in Ferrites Digest.

AN EXPERIMENTAL INVESTIGATION OF PHENOMENOLOGICAL DAMPING IN FERRITES

M. V. Kogekar and C. E. Patton
Department of Physics, Colorado State University
Fort Collins, CO 80523

A high sensitivity technique for the measurement of the microwave susceptibility as a function of applied static magnetic field has been traditionally used to investigate two-magnon losses and intrinsic losses in ferrites, through the determination of the effective linewidth parameter.[1] During the course of such measurements on hexagonal ferrites[2] and amorphous films,[3] it was realized that the technique also enables one to quantitatively determine the various phenomenological damping parameters which can be used to determine the relaxation of the magnetization vector and thereby provides a new and powerful way to examine the various forms of damping. The purpose of this work was to use the technique to determine which, if any, of the three most commonly used damping terms,[4] given by the Landau-Lifschitz parameter λ_{LL}, the Bloch-Bloembergen parameter $1/T_2$, and the complex frequency parameter η_{CF}, can be used to represent the intrinsic losses in ferrites.

The basic effect which leads to different possible results for different forms of the damping involves the lack of rotational symmetry, e.g., a thin slab magnetized in-plane or a planar magnetocrystalline anisotropy, for example. Susceptibility data were obtained following Ref. 1 for polycrystalline YIG spheres and thin plates and planar hexagonal ferrite spheroids. The various damping parameters were then obtained from these data. The frequency was 9.9 GHz and measurements were limited to high field, well above the ferromagnetic resonance field.

The fitted damping parameters vs. field for a YIG sphere and thin plate are plotted in Fig. 1, while Fig. 2 shows a similar plot for the hexagonal ferrite spheroid. Only the Landau-Lifshitz parameter λ_{LL} is independent of both the sample geometry and the applied field, and appears to represent correctly the intrinsic losses. Both the Bloch-Bloembergen parameter $1/T_2$ and the complex frequency parameter η_{CF} change markedly with field and sample geometry. This result is consistent with thermodynamic arguments on the form of the damping.

The authors are indebted to Mr. R. G. West, Trans-Tech, Inc., Dr. J. J. Green, Raytheon, Dr. Arthur Tauber, U.S. Army Electronics Command, and Mr. L. Reese Hodges, Trak Microwave Corporation for providing ferrite samples used in this study. This work was supported in part by U.S. Army Research Office, Contract DAAG-29-84-K-0172.

References

1. C. E. Patton and T. Kohane, Rev. Sci. Instr. 43, 76 (1972).
2. M. V. Kogekar and C. E. Patton, J. Mag. Magn. Mater. 54, in press (1986).

3. P. Kabos, T. Kato, T. Mizoguchi, and C. E. Patton, IEEE Trans. Mag. MAG 20, 1259 (1984).
4. C. E. Patton, Magnetic Oxides, D. J. Craik, ed. (John Wiley, London, 1975).

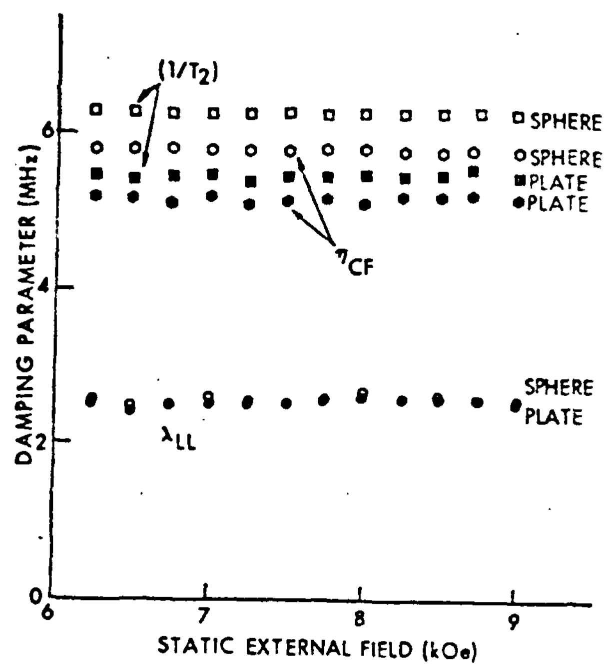


Fig. 1 Various phenological damping parameters as a function of applied static field for a YIG sphere and a thin plate.

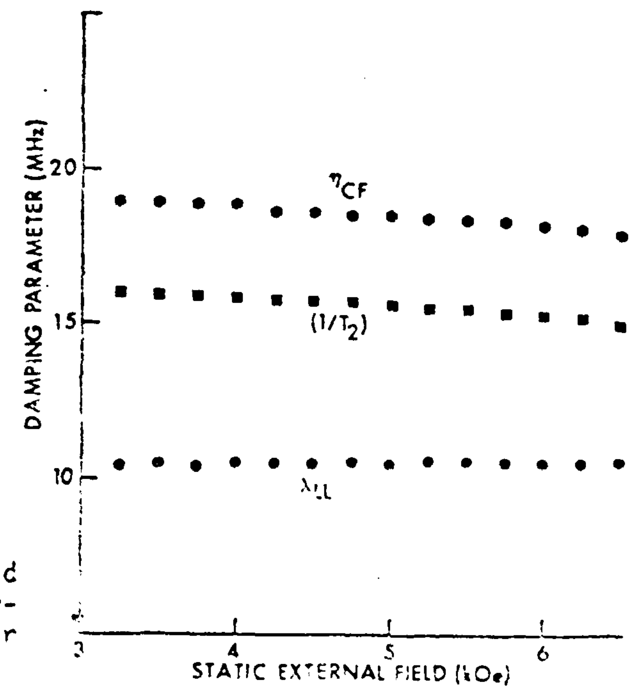


Fig. 2 Various phenomenolgical damping parameters as a function of applied field for MnZn-Y hexagonal ferrite spheroid with planar anisotropy.

III. PUBLICATION SUMMARY

(1) "Off Resonance Relaxation in Hexagonal Ferrites", M. V. Kogekar and C. E. Patton, J. Mag. Magn. Mater. 54-57, 1139 (1986).

(2) "An Experimental Investigation of Phenomenological Damping in Ferrites", M. V. Kogekar and C. E. Patton, digest accepted for presentation at the 1986 INTERMAG Conference, Phoenix, Arizona, April, 1986, manuscript in preparation.

III. PERSONNEL

The personnel supported on this project in one form or another (salary, materials, etc.) are listed below.

Principal Investigator:	Carl E. Patton Professor of Physics
Visiting Scientist:	You-Ting Zhang (SUST, Shanghai, PRC)
Postdoctoral Fellow:	Gopalan Srinivasan Ph.D., IIT-Bombay
Graduate Students:	Milind V. Kogekar (Ph.D. Candidate)
Fulbright Exchange Student:	Ronald Rossbacher (Univ. Regensburg, FRG)
Undergraduate Students:	Paul McClure (B.S., Physics, June, 1985)
	James Hannigan (EE/Physics Major)
	Robert Dutcher (Physics Major)
	Michael Roth (Physics Major)

END

DTIC

7-86